Laser Phosphorous Doping at High Scan Rates for Crystalline Junction Formation in Silicon/Perovskite Tandem Solar Cells

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Framework

- **The monolithically integrated 2-Terminal Si/perovskite tandem solar cell is currently considered the future device by the PV community, having the potential overcome the efficiency of Si single junction devices [1];**
- **The two sub-cells can be electrically interconnected using a recombination T-junction that needs to be produced using scalable and reliable processes;**
- **A T-junction made of crystalline Si offers several advantages compared to amorphous Si and TCOs, namely the expected higher stability upon further deposition of the perovskite sub-cell;**
- **Here, we attempt shallow doping of Si at atmospheric pressure using an IR laser as the heating source for the formation of crystalline n^{++} Si layers, giving the possibility of processing Si at speeds up to 5000 mm/s.**

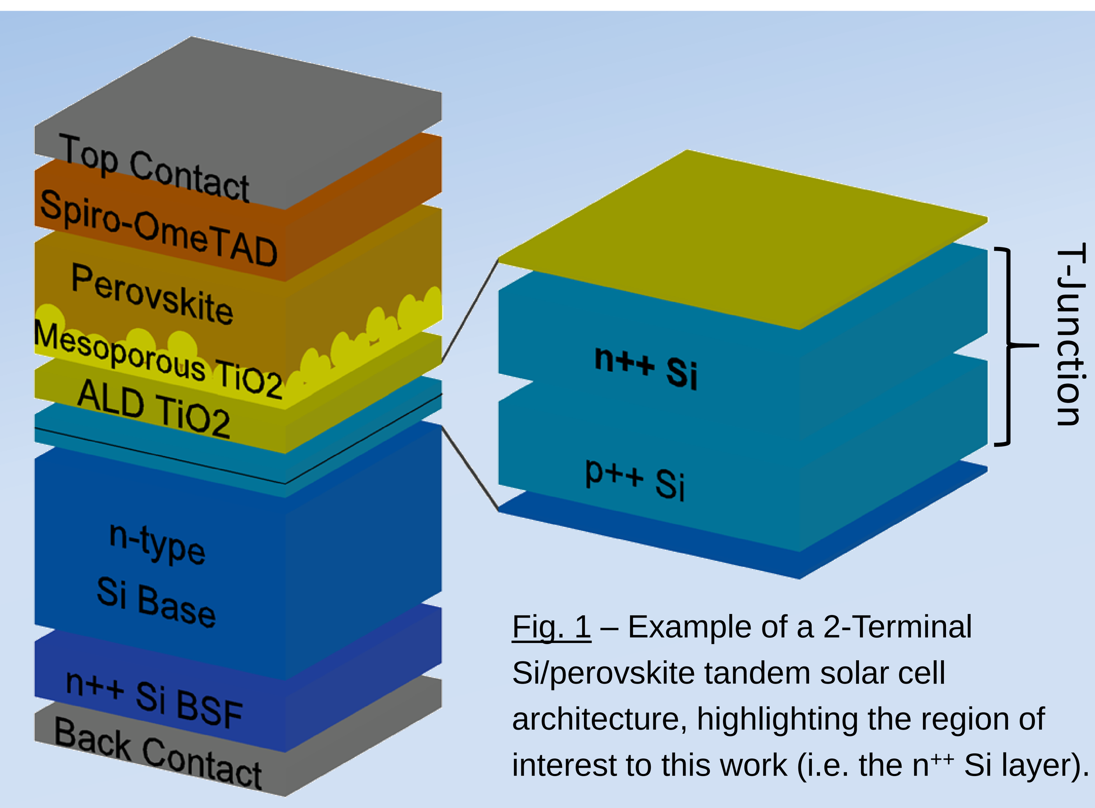

Fig. 1 – Example of a 2-Terminal Si/perovskite tandem solar cell architecture, highlighting the region of interest to this work (i.e. the n^{++} Si layer).

Laser doping setup

Process flow

1. Sample Loading
2. Chamber Cleaning – purging and pumping cycles
3. Setting chamber pressure to vacuum
4. POCl3/Argon mixture flow into chamber
5. Laser Rastering
6. Chamber Cleaning – purging and pumping cycles
7. Sample unloading and inspection

Sample details:

10 x 5 mm^2 areas were scanned on mirror-like Si using a constant energy density (E = 10.5 J/cm^2) with beam diameter of ca 20 µm and a combination of other laser parameters:

- ✓ scan speed: v = [1000 - 5000] mm/s;
- ✓ distance between lines d = [40 - 5] µm;
- ✓ number of scans: n = [1 – 3] times;

Setup schematic

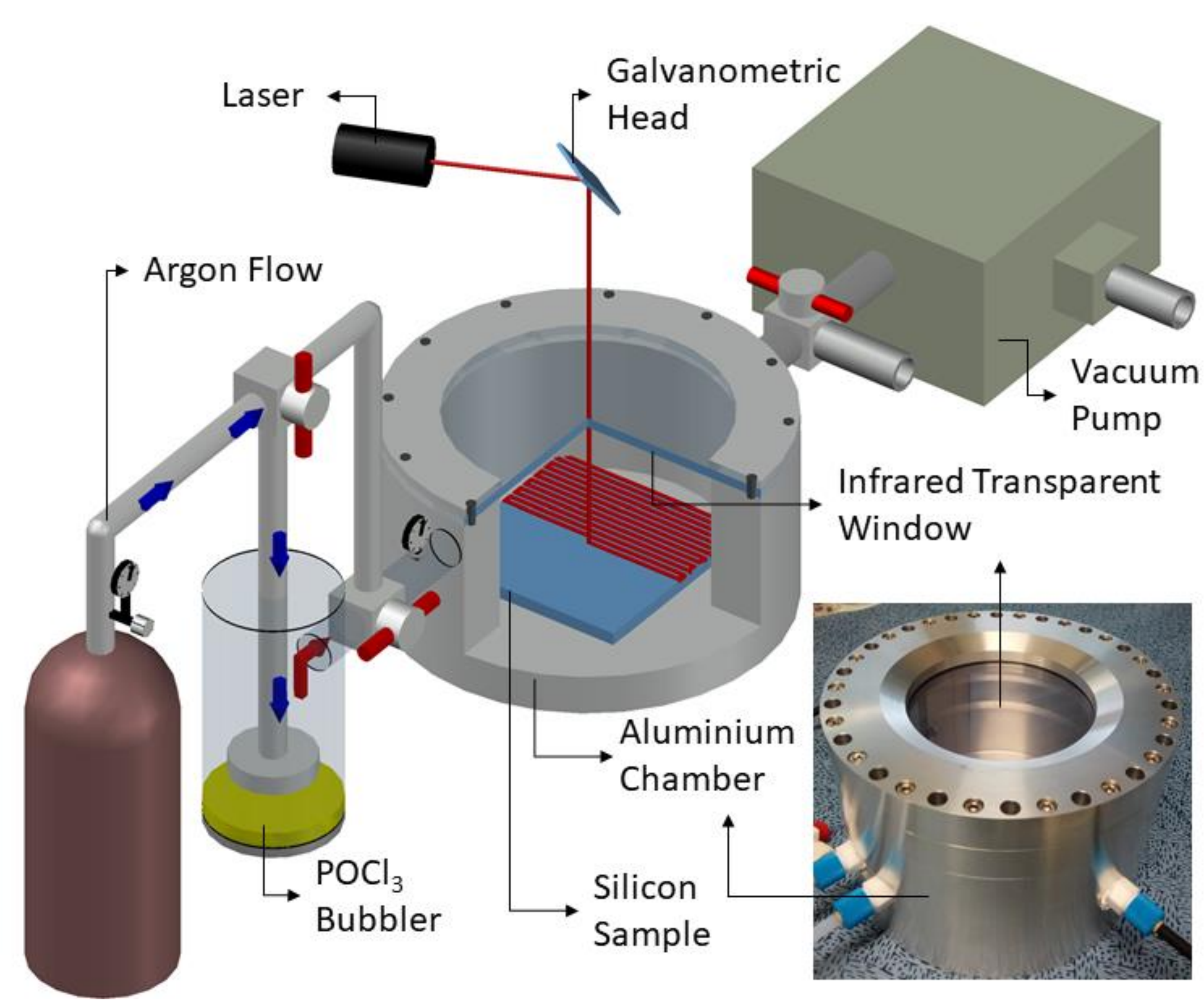

Fig. 2 – Schematic of laser doping apparatus developed to form tunnel junctions directly on p^{++} Si emitters. Blue and red arrows correspond to Argon and $POCl_3$/Argon mixture flows, respectively. A photo of the reaction chamber, with external diameter of 19 cm, is included on the bottom right-hand side of the schematic.

Shallow silicon melting

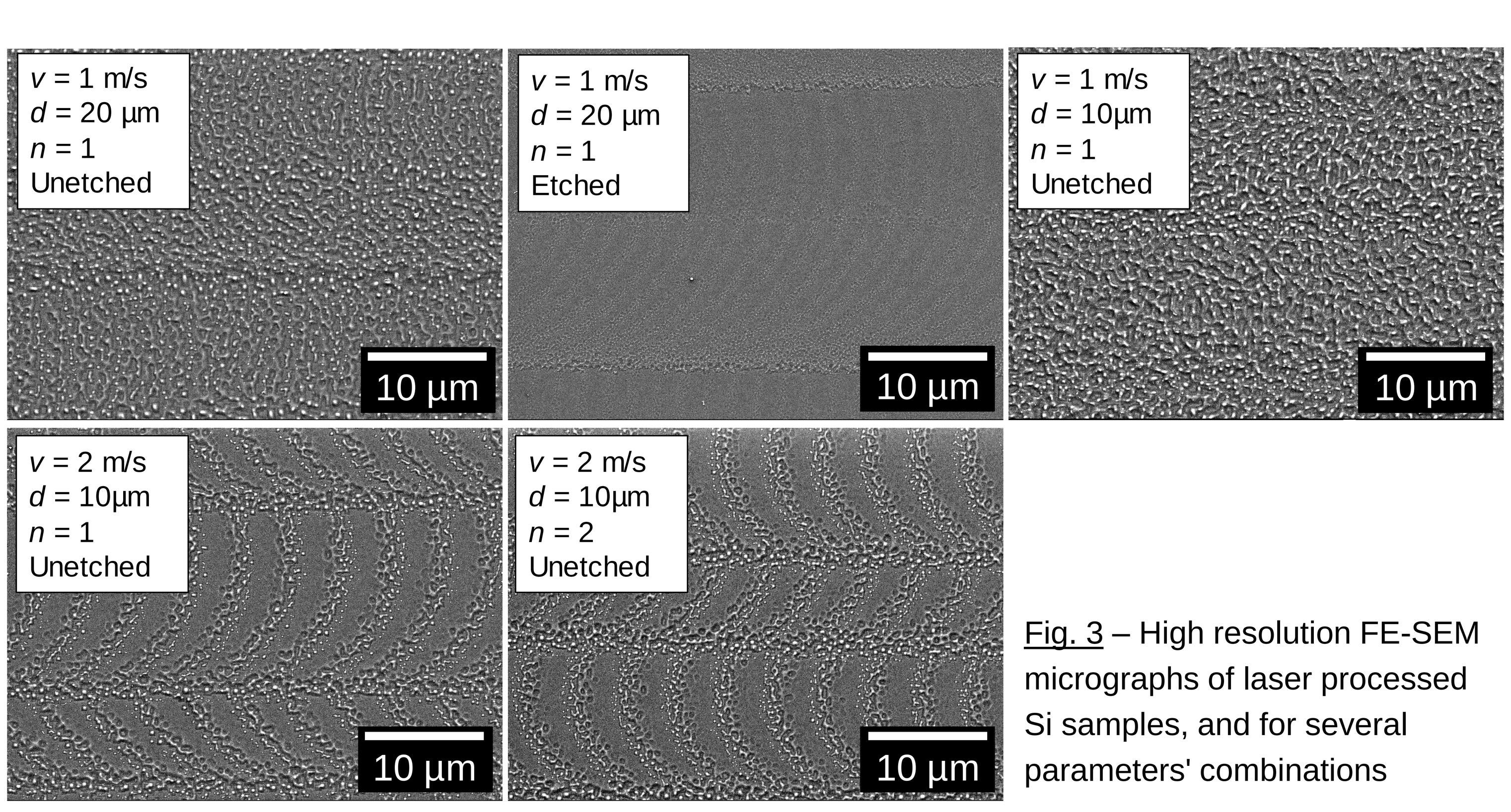

Fig. 3 – High resolution FE-SEM micrographs of laser processed Si samples, and for several parameters' combinations

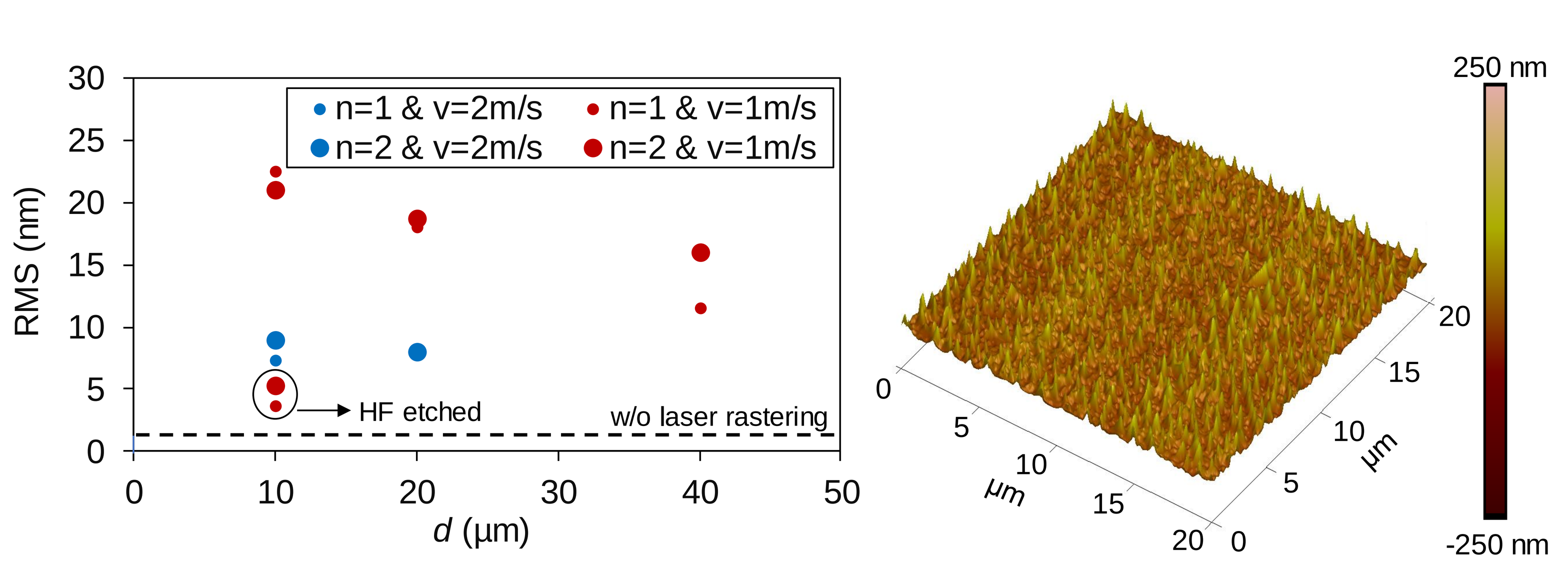

Fig. 4 – (left) Root mean square (RMS) as a function of d for different combinations of v and n, and sampling areas of 20 x 20 µm^2. (right) AFM 3D image of processed sample at v = 1 m/s, d = 10 µm and n = 1.

Phosphorus depth profiling

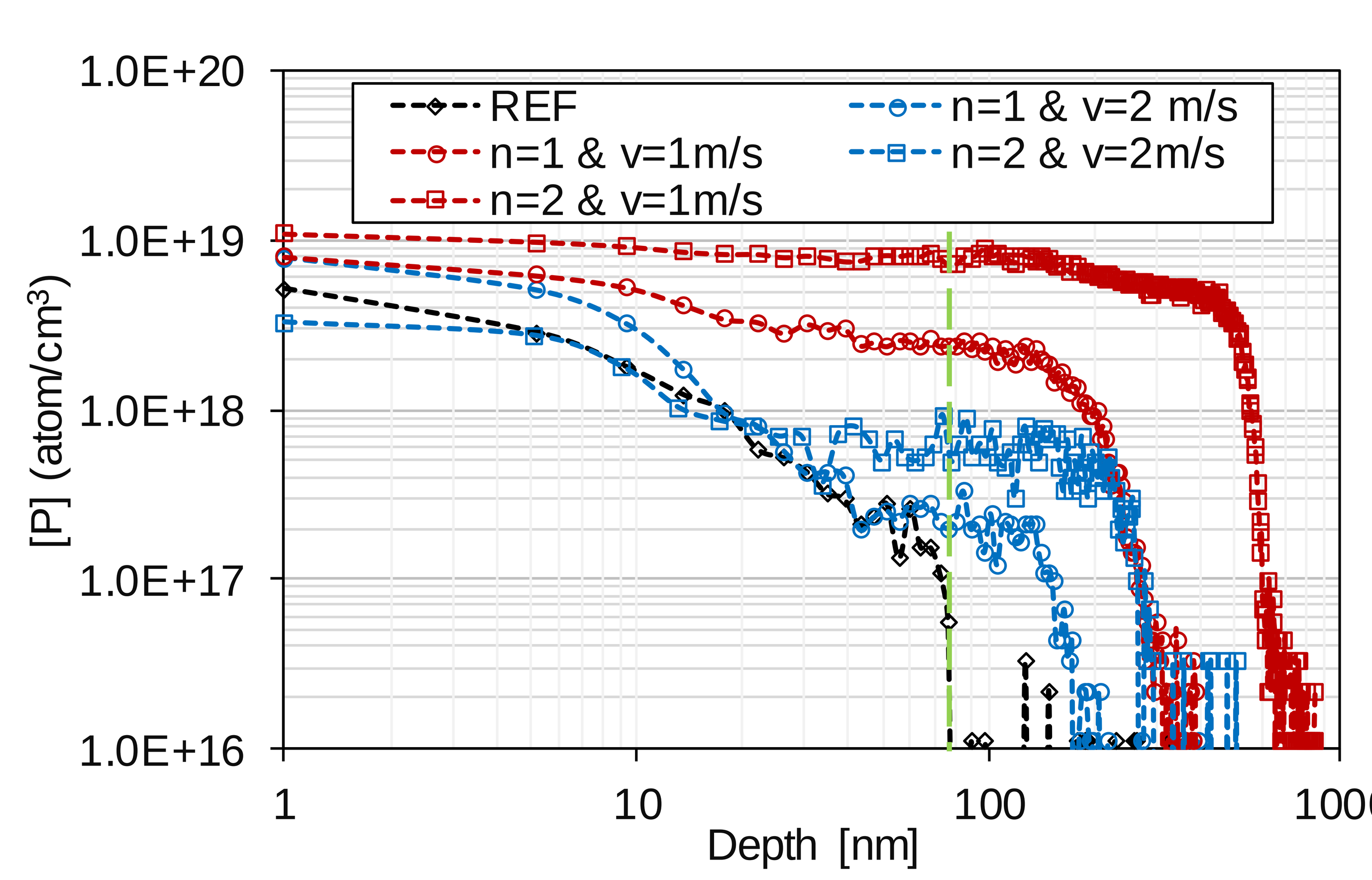

Fig. 5 - SIMS phosphorous depth profiles for unprocessed (REF) and laser processed samples at d = 10 µm and different combinations of v and n. Dashed green line delimits the $POCl_3$ adsorption at the surface.

Remarks

- **It was developed a setup that allowed shallow doping of Si wafers with phosphorous at the atmospheric pressure, as shown by AFM and SEM analyses;**
- **High phosphorous concentration was achieved, and preliminary SIMS data show a correlation between the laser processing parameters (e.g. number of scans) and the doping depth and peak concentration;**
- **Laser doping parameters must be further optimized to obtain thinner n^{++} Si layers and reduce $POCl_3$ adsorption at the surface, while etch-back strategies must be developed.**

[1] Z. Yu, M. Leilaeioun, Z. Holman, "Selective tandem partners for silicon solar cells", *Nature Energy* (2016) 1, 16137, doi: 10.1038/nenergy.2016.137.

Acknowledgements
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